Studies on Sonar Clutter and Reverberation

John R. Preston
Applied Research Laboratory
P.O. Box 30
State College, PA 16804
phone: (814) 863-1310 fax: (814) 863-8783 email: preston@ciao.arl.psu.edu

Grant Numbers: N00014-05-1-0156
http://www.arl.psu.edu

LONG-TERM GOALS

The long-term goals of this effort are to:

- Assess capability of directional arrays for inversion and reverberation studies

- Characterize acoustic clutter in a manner that will lead to its mitigation

- Improve geo-acoustic parameter extraction from reverberation data

- Construct suitable high fidelity reverberation and scattering models for model/data comparison and inversion

OBJECTIVES

The objectives of this effort are to:

- Use and continue to collect cardioid data from FORA and the NURC cardioid arrays, conduct cross frequency correlation studies of scattering features to assess the utility of this technology for reverberation and clutter analysis both in the cardioid frequency band and at lower frequencies.

- Continue the use of K-distribution-based techniques of Abraham to statistically characterize the various types of clutter seen on STRATAFORM especially the bio-clutter data from FORA.

- Continue validation and improvement efforts on a new reverberation model and the automated geo-acoustic parameter extraction technique from reverberation data.

- Operate, maintain and improve FORA hardware and data acquisition systems. Help plan and participate in ocean experiments in support of sea floor scattering, sonar clutter studies and ocean reverberation experiments.

APPROACH

There is a new 4-year Joint Research Program (JRP) with NURC, ARL-PSU, NRL, and DRDC Atlantic, of Canada. It is called Characterizing and Reducing Clutter in Broadband Active Sonar. Experiments are being designed to support the JRP (the PI is a member of this JRP). The most recent

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 2007	**Annual**	**00-00-2007 to 00-00-2007**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Studies On Sonar Clutter And Reverberation	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Applied Research Laboratory,P.O. Box 30,State College,PA,16804**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
code 1 only

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**8**	

experimental effort, called CLUTTER07, took place near the Malta Plateau area in May of 2007. It was focused on the physics based and the statistical characterizations of acoustic clutter for lower frequency sonars. The Five Octave Research Array (FORA) was one of two primary receivers for this experiment as well as for the BASE07 sea trial that immediately followed it.

The cardioid array section at the head of the FORA offers an improved way to study reverberation and scattering in shallow water. Some FORA cardioid data was collected in the 2006 Gulf of Maine experiment near Georges Bank, and a much more extensive set was taken in the 2007 CLUTTER07 and BASE07 experiments on the Malta Plateau. In addition much data has been taken using the NURC cardioid array in the same 2007 experiments and in the Boundary 2004 experiment on the Malta Plateau. These data are serving to test and improve the beamforming algorithms and data processing tools needed to better understand reverberation and scattering from towed arrays. The NATO Undersea Research Centre has shown examples of left-right rejections in excess of 15 dB on its cardioid array (NURC report SR-329A by D. Hughes). Recently the PI has verified that similar performance was observed using FORA during the 2003 Acoustic Clutter experiment. He has also shown there is usable left right discrimination down to ~600 Hz using the NURC array. The PI has completed an analysis of the normalization needed to provide calibrated levels out of cardioid arrays. Also shown was that the Hughes cardioid beamforming algorithm has an upper frequency limitation. (A manuscript with these findings has been accepted by the J.O.E.). Studies on wider band beamforming algorithms will be a focus of analysis on the 2007 data sets. It well known that often the same reverberation features can be observed over a wide range of frequencies. Objectives for this task will be to continue to correlate the high frequency unambiguous feature information from the cardioid data with the lower frequency bearing ambiguous information from line arrays and to define the circumstances under which good cross-frequency correlations exist.

The PI completed an initial effort to statistically characterize the clutter seen on STRATAFORM in the 2001 Acoustic Clutter Reconnaissance Experiment (ACRE) using methods developed by Abraham. Results, showed many data segments of matched filtered amplitudes to be non-Rayleigh and that the bistatic data were significantly more non-Rayleigh than the monostatic data. The non-Rayleigh behavior is consistent with the spikiness seen in much of the 2001 ACRE polar displays. Much of the observed statistical differences between various data segments can be explained by considering differences in multipath, amounts of bottom insonification and the overall sound speed structure. New work on the 2003 STRATAFORM data showed reverberation there to also be very non-Rayleigh (median shape parameters approximately unchanged from 2001). However, they had larger average scatterer size, which was consistent with observed fish schools that were more massive than in 2001. This work will be extended to include a statistical characterizations of the fish dominated scattering vs. the bottom-dominated regions to try to discriminate the two different types of clutter.

In the past the towed array based inversion algorithms developed by the PI used bearing ambiguous diffuse reverberation data and therefore were not able to map extracted geo-acoustic parameters in more than a spatially averaged sense when reverberation was anisotropic. New inversion work using directional cardioid data should be evaluated for the expected improvement in inversion quality vs. bearing.

A new faster and simpler range-dependent reverberation model is in development (together with Dale Ellis of DRDC who is working jointly with the PI) and will serve as the forward model engine for the simulated annealing based inversion scheme already in use. It is expected that refinements to that model will continue under this effort. Examples from the new reverberation model were presented at

the 2006 ONR Reverberation Modeling Workshop in Austin, TX and in more detail at the 2007 Underwater Acoustics Measurements (UAM) Conference in Crete.

WORK COMPLETED

Under cardioid data analysis the main work during this period centered on responding to reviewer comments on the paper described next. From that paper (submitted to the Journal of Oceanic Engineering), some directional characteristics of observed clutter and reverberation were presented using new cardioid receiving line arrays. It was shown that the cardioid arrays break the left-right ambiguity for reverberation sources above ~600 Hz. Broadband data were taken from two recent experiments. One was the 2004 Boundary Characterization Experiment near the Malta Plateau. That experiment was led by the NATO Undersea Research Centre (NURC). The area is rich in clutter objects like wrecks and mud-volcanoes and has some sub-bottom features that may be important. Sources were monostatic coherent pulses and SUS. The receiver was the NURC cardioid array. The other experiment was ONR's 2003 Geoclutter effort to study shallow water bottom reverberation and clutter in the STRATAFORM area off New Jersey. That experiment was led by M.I.T. Sources were bistatic coherent pulses. The receiver was the Five Octave Research Array (FORA). The STRATAFORM area is known to have benign surface morphology but strong clutter is observed. Some highlights of the reverberant returns from that area were discussed that include the correlation of returns from probable fish schools. Examples from the data analysis were presented using a cardioid beamforming algorithm developed by researchers at NURC but normalization for the algorithm was derived by the PI and some frequency limitations were noted. Also a constrained simulated annealing inversion technique was applied to the directional reverberation data. A two-layer fluid model of the bottom was assumed. The algorithm is best at estimating compressional speeds, layer thickness and attenuations. Extracted bottom parameters at the site were compared with independent inversion results from Holland. Inverting reverberation from directional arrays leads to better quality results since unlike standard line arrays, the reverberation data apply to only one bearing along the seafloor.

Using the 2004 reverberation data the PI has recently been helping Charles Holland to extract selected time series and other characteristics used in computing target strengths from mud volcanoes and other clutter sources on the Malta Plateau (manuscript submitted to JASA).

For the 2007 CLUTTER07 and BASE07 experiments on the Malta Plateau with NURC, the PI acted as Chief Scientist for the R/V Oceanus. As such he spent a significant portion of his time in the planning of the trial experiments with NURC, coordinating with PIs riding R/V Oceanus, and with experiment track designs. He also participated in these experiments spending over 40 days onboard R/V Oceanus. These experiments were designed to measure bottom clutter using a variety of source receiver geometries and source bandwidths. This data set also represents a much more complete cardioid data collection effort using the FORA. In this time period, additional new pieces of software were developed by the PI to process data from the FORA more rapidly.

The FORA was used as the primary receiver in a new experimental component of an initiative to study fish schools with remote sensing in the 2006 Gulf of Maine Experiment. This work was written up in a Feb. 2006 article in Science featuring images using FORA. The PI has also spent some effort in overseeing the ‘care and feeding’ of the ONR FORA at Penn State in preparation for the 2007 experiments with NURC mentioned above. In addition, plans for a FORA refurbishment effort under a new DURIP were developed to prepare for the 2009 NPAL/SPICE/LOAPEX follow-on experiments.

Efforts to develop a range dependent normal mode based reverberation model (in collaboration with D. Ellis of DRDC) have continued. Westwood's ORCA (JASA 1996) is used to generate the eigenvalues and eigenfunctions for an environment and then modifications to Ellis' techniques (JASA 1995) have been used to build the reverberation model using Matlab. Some results were presented and submitted at the ONR Reverberation Modeling Workshop held in the fall of 2006 and at the 2007 Underwater Acoustics Measurements (UAM) Conference in Crete. The most recent efforts have been focused on adding the time spread and dispersion corrections used by LePage (JASA 1999) to the model.

RESULTS

Below is a recent result showing reverberation using the cardioid array from FORA on one of the BASE07 extended experiments.. Figure 1 shows a polar display of bistatic reverberation from the Malta Plateau vs. angle and range. Data was collected on the FORA cardioid towed array in a 1000 Hz band centered at 2500 Hz. Reverberation intensity is color-coded vs. location. The source was an LFM pulse, 1 s in duration. Left-right ambiguity is broken by the cardioid beamformer and shows excellent left-right rejection on various clutter features that are most likely from mud volcanoes and carbonate mounds.

Figure 2 shows a reverberation vs. time model-model-data comparison at 630 Hz between the PI's new ORCA-Matlab based reverberation model (three receiver depths), the Generic Sonar Model and a Boundary 2004 data sample from a 84 element line array. The model-data match seems quite reasonable after 2 s.

IMPACT/APPLICATIONS

A better understanding of sonar clutter is key to improving sonar performance in shallow water. The new FORA and NURC cardioid arrays are exciting new tools for ocean acoustic researchers. A wide area-averaged bottom parameter estimation technique such as described above and that utilizes directional reverberation measurements could provide a quick way to estimate bottom parameters and hence give improved sonar performance estimates.

TRANSITIONS

Inversion techniques similar to those described above have recently been applied to select data from recent HEP experiments as part of ONR 6.2 efforts led by Dr. R. Wayland in support of the TAMBDA program at NAWC. In addition, an effort is underway to incorporate the above inversion concepts and reverberation models into a multi-static parallel toolbox – an effort that is being led by J. Joseph at NAWC.

The 2007 CLUTTER07 and BASE07 experiments on the Malta Plateau have produced a large quantity of high quality data that will help ONR researchers to understand and eventually mitigate sonar clutter.

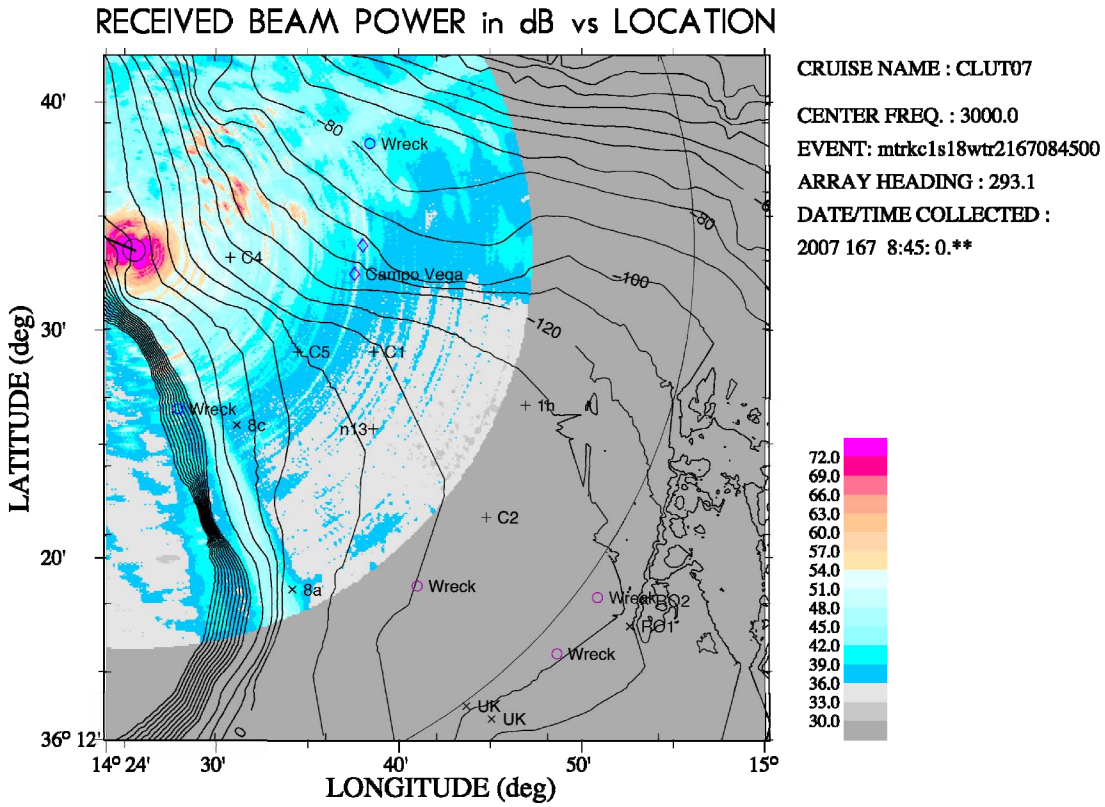

Fig. 1. Polar plot of the bistatic reverberation on the FORA cardioid array from a 1s LFM pulse on the Malta Plateau in the 2500–3500 Hz band. Levels indicated by color scale are in dB//1μPa^2/Hz. The array heading is 293°T. Left-right ambiguity is broken by the cardioid beamformer and shows excellent left-right rejection on various clutter features (most likely carbonate mounds and mud volcanoes).

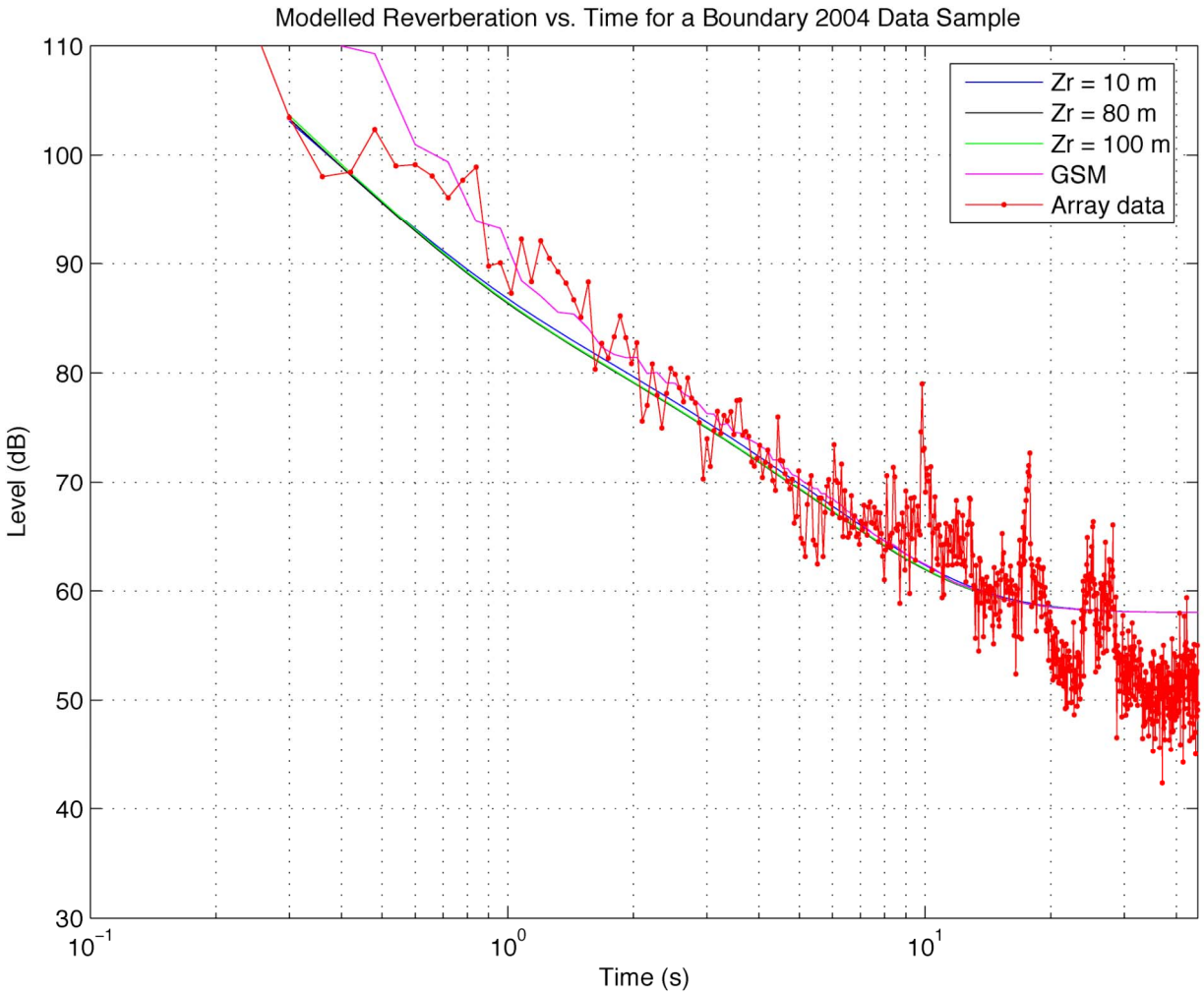

Fig. 2. A Reverberation vs. time model-data comparison at 630 Hz between the PI's new ORCA-Matlab based reverberation model (three receiver depths), the Generic Sonar Model and a Boundary 2004 data sample from NURC's 84 element line array.

REFERENCES

[1] J. R. Preston and D. D. Ellis, "A Matlab and normal mode based reverberation model," 2nd International Conference on Underwater Acoustic Measurements: Technologies and Results, Heraklion, Greece, June 2007.

[2] J. R. Preston and D. D. Ellis, "A normal mode and Matlab based reverberation model," Paper for the ONR Reverberation Modeling Workshop proceedings, Apr. 2007.

[3] J. R. Preston and D. D. Ellis, "Model Summary of NONAME," Presentation for the ONR Reverberation Modeling Workshop in Austin, Nov. 2006.

[4] J. R. Preston, Statistical characterization of sonar-like clutter observed on the STRATAFORM during the 2003 Acoustic Clutter Experiment in the 400–1500 Hz region, Paper 5aUWb1 for 151st ASA meeting in Providence, RI, June 2006.

[5] E. L. Hamilton, "Geoacoustic modeling of the seafloor," *J. Acoust. Soc. of Am.*, **68**, 1313-1340, 1980.

[6] H. Weinberg, The Generic Sonar Model, Naval Underwater Systems Center, New London, CT, USA, Technical Document 5971D, June 1985.

[7] P. Mourad and D. Jackson, "A model/data comparison for low-frequency bottom backcatter," *Journal of the Acoustical Society of America*, **94**, 344-358, 1993.

[8] E. K. Westwood and C. T. Tindle and N. R. Chapman, "A normal mode model for acousto-elastic ocean environments," *J. Acoust. Soc. Am.*. **100**, 3631-3645 (1996)

[9] R. B. Evans, "A coupled mode solution for acoustic propagation in a waveguide with stepwise depth variations of a penetrable bottom," *J. Acoust. Soc. Am.*, **74**, 188-195 (1983).

[10] D. D. Ellis, "A shallow-water normal-mode reverberation model," *J. Acoust. Soc. Am.*, **97**, 2804-2814 (1995).

[11] J. R. Preston, D. D. Ellis and R. C. Gauss, "Geoacoustic parameter extraction using reverberation data from the 2000 Boundary Characterization Experiment on the Malta Plateau," IEEE *J. Oceanic Engineering*, Oct. 2005.

[12] D. D. Ellis and J. R. Preston, "Extracting bottom information from towed array data," Rapid Environmental Assessment Conference, Sponsored by NURC, Lerici, Italy, 25-27 September, 2007.

[13] K. D. LePage, "Bottom reverberation in shallow water: coherent properties as a function of bandwidth, waveguide characteristics, and scatterer distributions," *J. Acoust. Soc. Am.*, **106**, 3240-3254 (1999).

[14] D. T. Hughes, "Aspects of cardioid processing," SACLANT Undersea Research Centre, La Spezia, Italy, SACLANTCEN Rpt SR329A, 2000.

[15] D. D. Ellis and J. R. Preston,"A comparison of broadband reverberation and clutter data from two directional arrays on the Malta Plateau," presented at 2nd International Conference on Underwater Acoustic Measurements: Technologies and Results, Heraklion, Greece, 25-29 June 2007.

PUBLICATIONS

C. W. Holland, J. R. Preston and D. A. Abraham, "Long-range acoustic scattering from a shallow-water mud-volcano cluster," *J. Acoust. Soc. Am.*, [submitted, refereed].

J. R. Preston and D. D. Ellis, "A normal mode and MATLAB based reverberation model," to appear in *Reverberation Modeling Workshop 2006*, J. Perkins and E. Thorsos, eds., NRL Report, Washington, DC, 2007. 15 pp. (DRDC Atlantic SL-287, July 2007). [in press].

J. R. Preston, “Using cardioid arrays for reverberation analysis and inversions” *J. Oceanic Engineering*, 2006 [in press, refereed].